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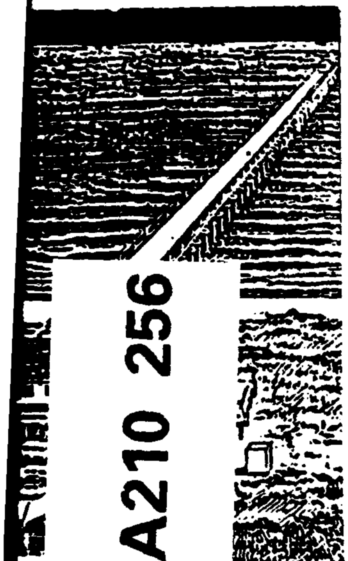
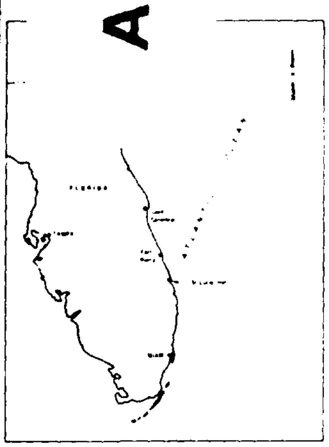
TECHNICAL REPORT CERC-89-6

POSSIBLE INTERCHANGE OF SEDIMENTS BETWEEN A BEACH AND OFFLYING LINEAR SHOAL





by

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An investigation of Gilbert Shoal, a typical nearshore linear shoal on the Florida Atlantic coast, was undertaken to determine if significant interchange of sediments occur between the shoal, the surrounding seafloor, and the adjacent beach. The principal study technique ~~of study~~ made use of selected sediment particle types or particle characteristics as natural tracers. Seven tracer elements and two particle characteristics were of some use.

It was found that some sediment from the shoal reaches the beach, but the amounts involved are small and most of the beach sediment comes from littoral drift, organic shell production on the lower beach and nearshore area, and breakdown of coquina rocks of the Anastasia Formation which crop out on the beach and in the nearshore zone. Gilbert Shoal and the surrounding seafloor apparently receive little, if any, sediment from the beach or nearby St. Lucie Inlet. Gilbert Shoal sediment appears to be derived from the nearby shelf floor and from in situ shell production. Keywords

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PREFACE

This study was conducted under the work unit "Barrier Island Sedimentation Studies" of the Shore Protection and Restoration Program of the US Army Corps of Engineers by the US Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC). The report was prepared by Mr. Edward P. Meisburger, CERC, under the general supervision of Dr. Suzette Kimball, Chief, Coastal Morphology Unit; Mr. H. Lee Butler, Chief, Coastal Processes Branch; and Dr. James R. Houston, Chief, CERC. John Lockhart and John Housley were technical monitors.

Commander and Director of WES at the time of publication was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows.

Multiply	By	To Obtain
feet	3.28084	metres
inches	0.0393701	millimetres

POSSIBLE INTERCHANGE OF SEDIMENTS BETWEEN A BEACH AND OFFLYING LINEAR SHOAL

PART I: INTRODUCTION

Background

1. Linear shoals are a prominent feature of the continental shelf off the US Atlantic coast (Moody 1964; Uchupi 1968; Macintyre and Milliman 1970; Duane et al. 1972; Swift et al. 1972a; Stahl, Kozan, and Swift 1974; Swift et al. 1972b; Swift, Duane, and McKinney 1974; Sheridan, Dill, and Kraft 1974; Palmer and Wilson 1975; Swift et al. 1976; Swift et al. 1978). Some early investigators of these shoals assumed that they were drowned barrier islands dating from the Holocene transgression (approximately 18,000 to 4,000 years before present) during which postglacial sea level rose from the low late-Wisconsin elevation to near its present stand (Field et al. 1979). More recent studies suggest that most are posttransgressive submarine shoals created largely by storm-generated current flow (Duane et al. 1972; Swift, Duane, and McKinney 1974). Linear shoals are of interest to coastal engineers because they form large reservoirs of clean sand suitable for beach restoration and periodic nourishment. In addition, these shoals may affect the siting and design of channels and offshore structures.

2. Studies of linear shoals indicate that they consist of ridges of unconsolidated sand-size sediment, usually with the long axis in a general northeast-southwest alignment. Two types of linear shoals occur: shoreface connected shoals in which the landward part merges with the shoreface, and isolated or detached shoals which lie seaward of the shoreface on the shelf floor. In places, these isolated shoals extend almost to the shelf edge.

3. Linear shoals, particularly those close to shore, are attractive sites for sand-borrow operations. It is important to know if removing material from the shoal would have adverse effects on the beach or nearshore sedimentation systems. There are three possible effects that warrant concern. The first of these is that dredging of shoal material might lower the crest elevation such that additional wave energy is passed on to impinge on the nearby shore with consequent increased potential for erosion. A second

possible adverse effect on the local sedimentation regimen could occur if the shoal acted as a conduit for transferring sand from the shelf floor to the shore and nearshore deposits. In this situation, sand that otherwise would nourish the beach would be trapped in the borrow pits until the shoal returned to the equilibrium condition that existed prior to dredging. A third and similar possibility would be a situation in which seasonal movements of sediment between the beach and shoal occurred with sand being transferred from the shore or shoreface to the shoal during one season, and returning to the shore in another. If material were dredged from the shoal, some or all of the seasonal input of sand from the shore or shoreface might be trapped and not return to shore. One approach to examine these possibilities is to establish the extent, if any, of sediment interchange between the beach and offshore environments.

4. This study examines evidence pertaining to these questions from Gilbert Shoal, a linear shoal near St. Lucie Inlet on the Atlantic coast of Florida (Figure 1). This shoal and its immediate environs were cored extensively in 1978 by the US Army Engineer District, Jacksonville (SAJ), in connection with the Martin County Beach Erosion Control Study. Samples from the cores provided to the US Army Engineer Waterways Experiment Station Coastal Engineering Research Center (CERC) by SAJ furnished an economical resource for investigating questions pertaining to sediment interchange between the shoal and adjacent beach. Sets of samples from the shore adjacent to Gilbert Shoal were collected by CERC for this study in September 1981 and 1982.

Approach

5. The basic approach to determine if either transport or interchange of sediments takes place between Gilbert Shoal and adjacent beaches was based on the occurrence of natural tracers. Natural tracers are particles in a sediment deposit that can be used to identify the source from which the material was derived. The most commonly used natural tracers are heavy minerals, but other components such as oolites and glauconite pellets have been used.

6. Initially, samples from the beach and shoal were examined microscopically to identify and classify their separate constituents. From this initial analysis, grain types that were potentially usable as natural tracers were selected. Potentially useful tracers are considered to be particles that

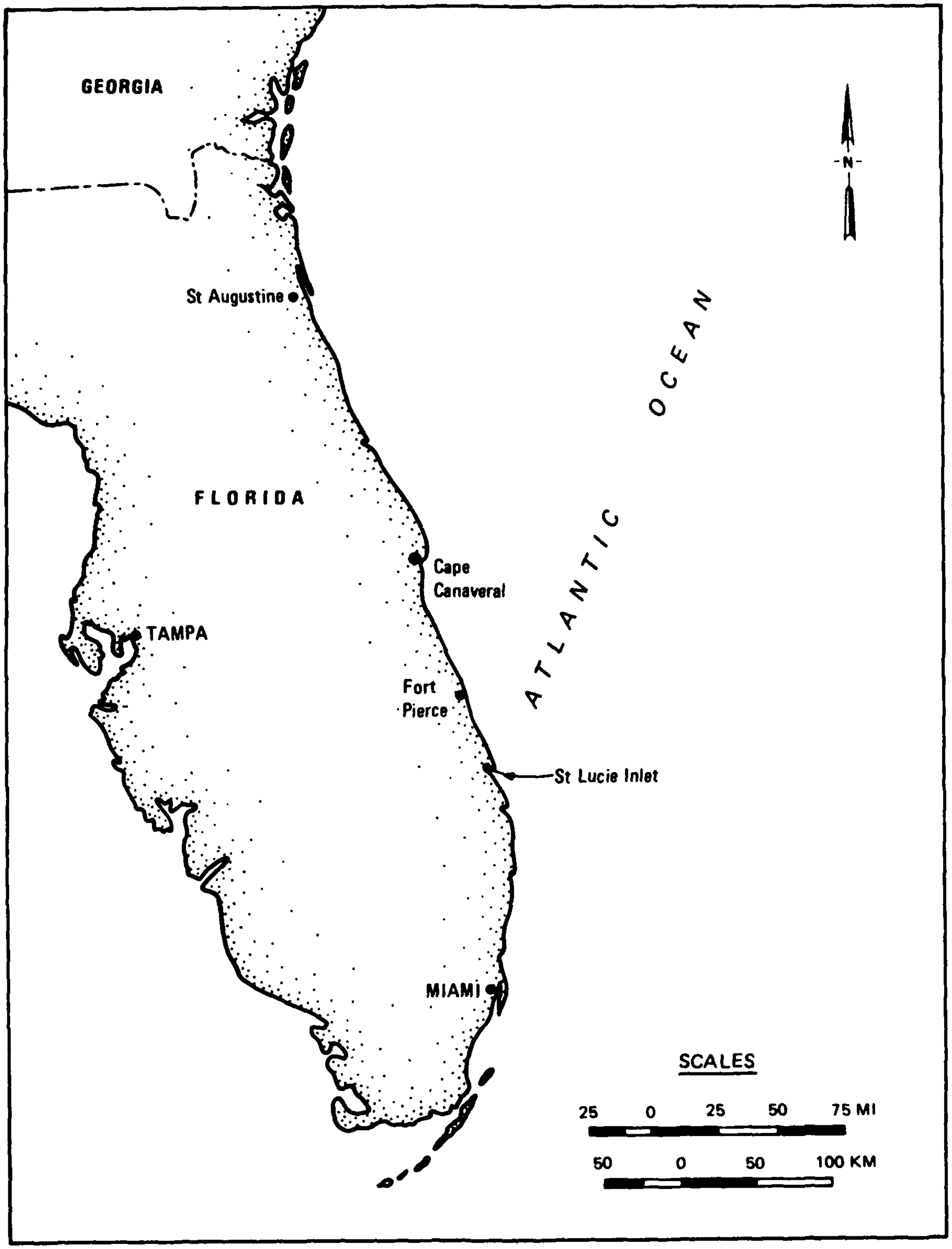

Figure 1. Location map of the study area

possess unique, identifiable features that would not easily be lost even after fracture and abrasion during transport. In addition, they are present in at least one environment in sufficient numbers so that small random variations in frequency are not significant in making comparisons.

7. Once selected, the tracer elements were counted and their frequency determined in samples from the beach, shoal, and seafloor areas surrounding the shoal. It was expected that if there was little or no interchange of sediment between environments, certain types of particles would occur in one environment and either not occur or have a substantially different frequency in the other environments. If, however, the types and abundance of tracer elements were more-or-less equivalent in any two environments, it is reasonable to assume that either transport or interchange of sediment does take place between the environments or that both environments have a common source.

8. The validity of these assumptions depends on the premise that selective sorting or destruction of specific grain types does not significantly alter the amount of a given tracer during transport from source to deposit. To reduce the possibility of selective sorting by size, each sediment sample was divided into five size fractions to decrease the size range of particles being compared. Tracer elements in each size fraction were thus analyzed and counted separately, and comparisons were made only between equivalent size fractions.

PART II: GILBERT SHOAL

9. Gilbert Shoal lies immediately north of St. Lucie Inlet which is located on the Atlantic coast of Florida about 35 km south of Fort Pierce (Figure 1). It is a complex two-part shoal consisting of two offset ridges connected by a narrow saddle (Figure 2). The inshore ridge is nearly shore parallel, 2,900 m long and centered about 1,150 m offshore. Most of the

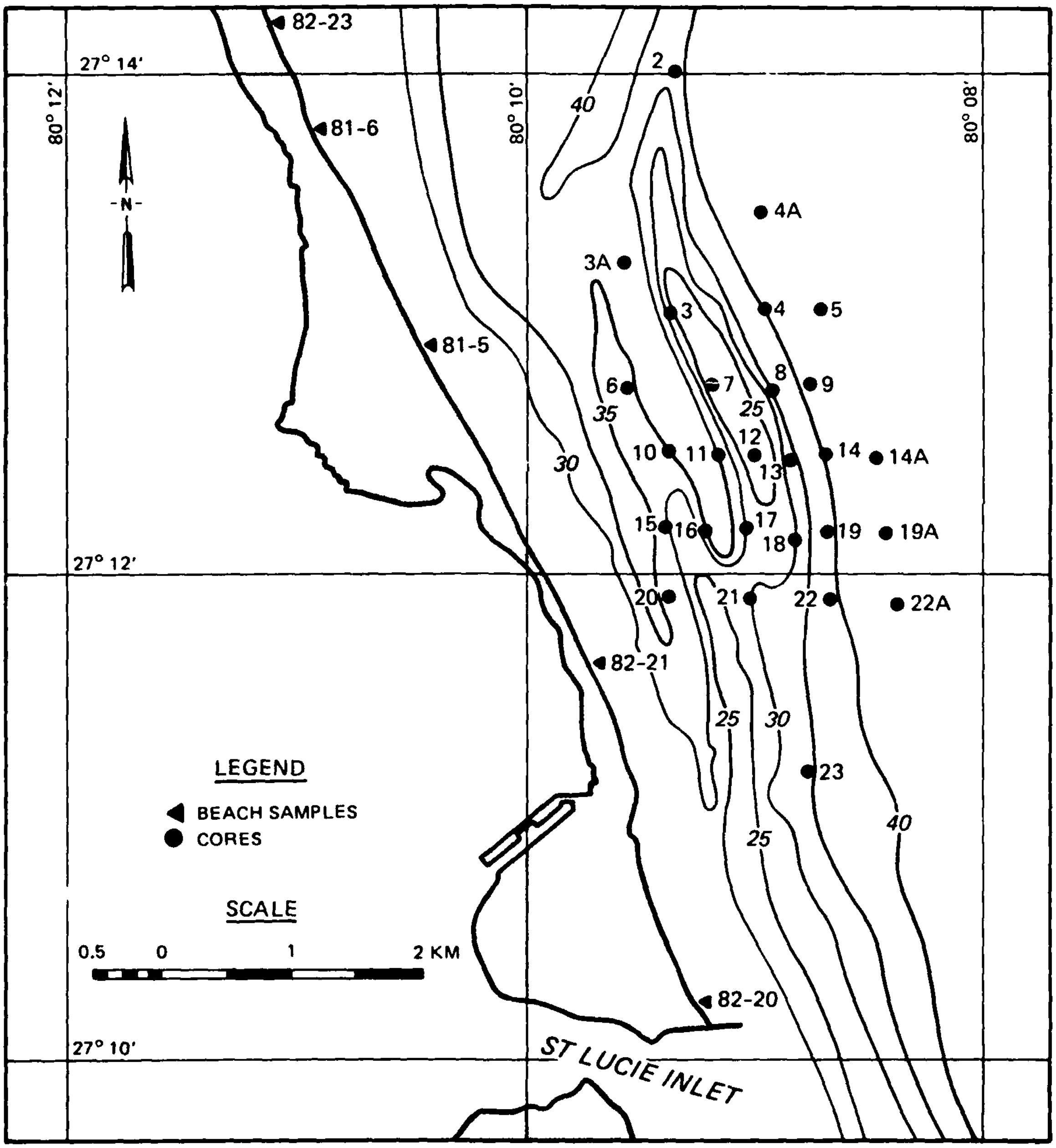

Figure 2. Bathymetry and sample locations (contours are measured in feet)

inshore ridge is within the shoreface zone of the adjacent coast. The outer ridge is also nearly shore parallel. It is 4,000 m long and is centered 1,900 m offshore. Both ridges crest at a depth of approximately 7.6 m and have a relief above the surrounding seafloor of about 5 m.

10. The outer shoal can be classified as an isolated shoal, although a topographic connection still exists with the inner shoal by way of the narrow saddle. The outer ridge may be in the process of detachment from the shoreface as described by Duane et al. (1972); Swift, Duane, and McKinney (1974); and Swift et al. (1978).

11. Gilbert Shoal is the southernmost shoal in a field of linear shoals that extends northward past Fort Pierce to the vicinity of Vero Beach (Meisburger and Duane 1971). Sediments in the shoal consist mainly of quartz and organic calcium carbonate shell fragments. Beach sands on the adjacent shore are similarly composed of quartz and organic calcium carbonate but are much higher in quartz content than the shoal deposits. Coquina rocks of the Pleistocene Anastasia Formation crop out at places on the beach. These rocks probably are also exposed in the sublittoral nearshore area. Numerous pieces of fine-grained, muddy, sandy limestone also occur in the detritus which litters the beach. The identity and age of this rock are not known. Presumably it is exposed offshore as no exposures were noted on the shore.

PART III: SAMPLE PROCESSING AND ANALYSIS

Data Collection

12. Cores of the Gilbert Shoal area were taken in June 1978 by SAJ in connection with the Martin County Beach Erosion Control study. Samples were taken from the top of each core and at selected intervals downhole to obtain representative material from the surficial layer and underlying layers within core penetration range. In addition, where the surficial layer was thick (as in the case of shoal cores), samples from various intervals within the layers were obtained.

13. Samples at five sites on the beach adjacent to Gilbert Shoal were collected in September 1981 and 1982. At each site sampled in 1982, five samples were taken: (a) from the turbulent zone where the wave backrush meets the incoming uprush; (b) from the existing limit of uprush; (c) from just below the high water (HW) line; (d) from an 18-in.-deep* hole on the backshore; and (e) from the backshore surface. Samples collected in 1981 were from the backrush and HW line only. In addition, a representative collection was made of mollusk shells, rock fragments, and other detritus littering the beach surface.

Processing

14. All sand samples from offshore cores and beach locations were wet sieved on a US Standard 230 mesh sieve (0.0625 mm) to remove fines. Samples were then dried and split for analysis. One split was used for mechanical size analysis by sieve, while another was used for size analysis by a fall velocity type rapid sediment analyzer. A third split was prepared for analysis and identification of the various constituent particles to select potential tracers.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

PART IV: RESULTS

15. Analysis of sediment samples used for this study shows that a number of the particles contain distinctive features that can be used to classify them into genetic categories, for example, barnacle plates and oolites. In addition, certain particle attributes, independent of genetic type, such as roundness and surface texture can also be determined albeit by more subjective means. These characteristics can be useful for comparative analysis of particles that do not retain sufficient detail to determine a specific genetic class. In addition, the calcium carbonate/quartz ratio is a useful property of the sampled sediment, particularly in the smaller size classes where few particles are large enough to be identified.

16. The most useful types of particles for source analysis found in the sediments are barnacle plates and opercular valves, the pelecypod *Donax variabilis* Say and rock fragments. Secondarily useful types are mollusks, foraminifera, oolites, and nonopaque heavy minerals. Each of these types together with the calcium carbonate/quartz ratio and particle attributes is discussed in the sections following.

Carbonate and Quartz

17. Quartz grains and calcium carbonate make up 90 percent or more of the sediments both offshore and on the beach. Most of the calcium carbonate particles are derived from the hard parts of marine organisms. A relatively small number are fragments of calcareous rocks at least some of which are also biogenic.

18. The calcium carbonate percentage of each sample was determined by visual grain count under a binocular microscope. At least 300 grains were counted. A summary of results is in the tabulation on the next page. In compiling the tabulation, average values were used for all samples on the shoal, on the seafloor around the shoal, and at a number of sample sites on the adjacent beach. Data for sizes over 2.0 mm are not shown because there are no quartz grains this large in the samples. A series of tables representing basic data for the various core and beach samples used to calculate the average values are shown in Appendix A.

Sample Location	0.850-2.0 Carbonate	0.850-2.0 Quartz	0.425-0.850 Carbonate	0.425-0.850 Quartz	0.250-0.425 Carbonate	0.250-0.425 Quartz	0.125-0.250 Carbonate	0.125-0.250 Quartz
	Percent in Grain Size Range, mm							
Gilbert Shoal	100.0	0	91.8	8.2	73.5	26.5	73.7	26.3
Seafloor	99.9	0.1	95.2	4.8	79.6	20.4	61.6	38.4
Beach	96.2	3.8	65.0	35.0	36.6	63.4	31.5	68.5

19. Differences in the quartz/carbonate ratio are large for all size classes below 0.850 mm but are nearly equal in the larger fractions. This is probably due to the absence of a source for large quartz grains rather than the competence of transport mechanisms, at least in the littoral zone, where much larger carbonate particles are readily moved. In the two smallest size classes, quartz particles are two to three times as numerous in the beach sands as they are in offshore locales. In the 0.425- to 0.850-mm class, the quartz content of the beach is four to seven times as great as in the offshore deposits. This suggests that there is not a large amount of sediment interchange between the carbonate-rich offshore sands and the quartz-rich beach sediments.

20. A possible explanation for the difference in carbonate frequency is rapid degradation of the carbonates in the higher energy beach and shallow sublittoral environments. This is unlikely because degradation of carbonate particles in the two size classes over 0.850 mm, which are over 90 percent carbonate, would enrich the finer size classes where attrition rates decrease, thus adding considerably to the carbonate fraction. However, in the study area, sediments in the smaller size classes have considerably less calcium carbonate particles.

21. Another condition that could explain the differences in carbonate content would be preferential sorting of carbonate and quartz grains during transport. It seems unlikely that differences in specific gravity (sp gr) are large enough such that quartz (sp gr 2.65) would be transported at a significantly different rate from calcite (sp gr 2.72). Shape differences are another and probably more important factor. The calcium carbonate grains tend to have a flattened shape due to the form of the organisms from which they were derived, while the quartz grains are generally more equant. The effect of this would be to make the flattened particles, once entrained, more transportable, thus tending to enrich the carbonate fraction rather than the quartz content of the beach deposits.

Heavy Minerals

22. In sediments, heavy minerals are considered to be those having a specific gravity higher than some standard--usually 2.85. These minerals are customarily separated from the lighter matrix by a sink-float procedure using a heavy liquid such as bromoform (sp gr 2.85) or methylene iodide (sp gr 3.32). Heavy minerals have long been used in the study of sedimentary rocks as natural tracers and for correlation of strata. While of undoubted value for these purposes, heavy mineral data must be used with caution because the wide differences in specific gravity and grain shape lead to selective sorting during transport and deposition. In many cases, selective sorting significantly changes the nature and frequency distribution of the heavy mineral suite. Coastal plain deposits such as those described here usually have a limited suite of heavy minerals consisting of the harder and more stable common minerals. These minerals occur widely and are commonly found well disseminated, thus frequency distribution is the most important factor in analysis.

23. Data for heavy minerals in the study area are shown in Table 1. Only the nonopaque heavy minerals were analyzed because of the difficulty and special equipment needs in identifying most opaque minerals. Samples analyzed were from the shoal, the seafloor surrounding the shoal, the beach, and two types of rock found as detritus or in outcrops on the beach. The rocks are discussed in more detail in a later section of this study. Each heavy mineral sample was subdivided into three size classes for separate analysis to diminish the effects of selective sorting. Available samples from offshore areas and insoluble residues of the rocks were of such small size that most did not yield 100 or more heavy mineral grains in the size ranges greater than 0.125 mm. This small number was not considered adequate for analysis, and data for these samples are not shown in Table 1.

24. When considering the size of the heavy mineral grains, the lack of grains over 0.125 mm in offshore areas suggests that most of the heavy minerals on the beach over 0.125 mm were probably not derived from offshore deposits but from some other source. In samples that provided data for all three size ranges, there is an appreciable difference in assemblages related to size. Epidote, staurolite, tourmaline, and garnet are the principal species in size fractions greater than 0.125 mm, while below this size, the principal species are epidote and amphibole with zircon also being important in

Table 1

Average Percentage of Principal Heavy Minerals

Environment	No. of Samples Analyzed	No. of Samples With 100 Grains of Heavy Minerals	Mineral Species: Zircon	Rutile	Garnet	Staurolite	Epidote	Sillimanite	Amphibole	Tourmaline
0.250-0.425 mm Grain Size										
Shoal*	8	0								
Seafloor*	7	0								
Beach	17	3		0.5	15.3	42.4	25.1	2.0	0.7	13.7
Anastasia	9	0			4.1	24.5	33.8	4.1	2.8	30.3
Gray limestone*	7	0								
0.125-0.250 mm Grain Size										
Shoal*	8	0								
Seafloor*	7	0								
Beach	17	14	1.7	6.2	10.4	21.2	30.1	2.4	2.9	9.1
Anastasia	9	7	3.5	8.1	9.8	14.6	34.8	2.5	6.4	7.3
Gray limestone*	7	0								
0.063-0.125 mm Grain Size										
Shoal*	8	7	0.4	1.6	3.6	3.5	45.8	3.0	38.5	3.3
Seafloor*	7	7	0.2	0.3	1.2	2.0	44.6	4.6	32.5	2.0
Beach	17	7	22.2	6.9	4.3	7.8	39.0	2.4	14.0	3.0
Anastasia	9	9	3.8	5.6	3.8	5.3	51.2	5.9	19.4	4.7
Gray limestone*	7	7	0.2	0.8	1.0	3.4	44.0	5.2	43.1	2.2

* Sample size not adequate for analysis.

the beach samples. The increase in zircon with smaller size is probably due to the fact that this mineral commonly occurs in nature in small crystals.

25. Only eight heavy mineral species are present in the samples in quantities of 1 percent or more. These minerals occur in nearly all the samples but at different frequencies. The differences in frequency between sample elements may be caused by selective sorting. However, there are significant differences in zircon, rutile, garnet, and amphibole between the offshore and gray limestone samples, and the beach and Anastasia rock. This suggests that the beach sediment could be largely derived from disintegration of Anastasia rocks in onshore and sublittoral outcrops.

Rock Fragments

26. Fragments of calcareous rocks occur commonly in the beach sediments but are rare offshore (Table 2). Large pebble to cobble size rocks are fairly common in beach detritus and at outcrops that occur from place to place along the shore. These larger rocks and outcrops are similar to the fragments occurring in the sediment samples.

Table 2

Percentage of Rock Fragments in the Study Area

Sample Location	Fragment Size Range, mm				
	2.0-10.0	0.850-2	0.425-0.850	0.250-0.425	0.125-0.250
Gilbert Shoal	0	0.09	0.51	0.37	0
Seafloor	0.21	0.75	0.96	0.18	0
Beach	5.90	4.33	1.82	0.32	0

27. There are two principal types of rock occurring in the study area. The most common is a light-to-medium-brownish-colored, well-indurated, coarse coquina limestone. Available evidence indicates that the coquina is part of the Pleistocene Anastasia Formation (Cook 1945) which extends in a narrow band along most of the Atlantic coast of Florida north of Boca Raton. The second principal rock type is a light-gray, well-indurated, muddy, sandy limestone which is lithologically quite dissimilar to the Anastasia rocks. The origin and stratigraphic position of this rock are unknown. Large specimens of the

two rock types found in the beach drift have been penetrated by boring mollusks, sponges, and algae. This is probably the main mechanism for physical disintegration of the rocks, adding their fragments and constituent grains to the coastal sediments.

28. A third rock type seen only in smaller fragments in the sediment samples is a brown to gray oolitic limestone; these may have come from outcrops of the Miami oolite. Although Gilbert Shoal is well north of the occurrence of the Miami oolite on the coast (Cook 1945), the oolite may continue northward in the offshore area. Evidence for this comes from cores of the offshore shelf in the Fort Pierce area to the north which contains considerable amounts of oolite and poorly consolidated oolite limestone (Meisburger and Duane 1971).

29. Table 2 shows that rock fragments are common constituents in the beach sands but not in offshore locales. It seems reasonable to conclude that the Anastasia rock fragments are being produced from exposures on the beach and in shallow nearshore waters. The formation is known to be confined to a relatively narrow band along the coast and does not appear to occur very far seaward of the shore. The gray limestone was not seen in exposures on the beach.

30. Rock units were encountered downhole in several offshore cores. One type is a light-gray coquina limestone. This rock is similar to the Anastasia rocks found on shore, but the affinity is uncertain. In core number 6 (Figure 2), a well-indurated sandy limestone occurred 3 m downhole. This rock is similar in general character to the muddy sandy limestone found in the beach drift but differs by containing foraminifera and numerous oolites in the size fraction smaller than 0.250 mm. These rock units do not seem to have contributed rock fragments to the overlying sediments.

Mollusks

31. The sediments of both onshore and offshore sample locales contain large numbers of mollusk shells and shell fragments. These were compared to see if any species were unique, or nearly so, to one locale or another. The size fraction used for this analysis was the 2.0- to 10.0-mm range. The upper limit was used because larger shells and fragments were rare in the sparse amount of sample material from the offshore cores. The lower size limit was

used because there is a substantial decline in identifiable fragments below this range. Even in the fraction used, only a modest number of the calcareous particles were identified as to genus, although the majority of particles are probably derived from mollusks.

32. In addition to the sand samples from the beach, a representative sample of whole mollusk shells was collected from the beach drift at each sampling station. Not all of the species found in the sediment samples appeared in the beach drift sample; for the most part, these are small pelecypods that might have been overlooked. Some species found in the beach drift were not identified in the 2.0- to 10.0-mm fraction. These are very common species and in all likelihood provide a substantial number of particles; however, their fragments are not as easily identified as those of other species. A more detailed study of surficial sculpture and other details of the shell structure could probably increase the number of identified particles.

33. All but one of the more common mollusks in the study area are pelecypods, the only common gastropod being *Crepidula fornicata* (Linné). Other gastropod species are present in small numbers but were not identified.

34. Table 3 shows the average frequency of mollusk species on Gilbert Shoal (cores 3, 7, 11, 12, 15, 17, and 20, Figure 2), in cores surrounding Gilbert Shoal (all other cores), and in beach samples. All of the species identified are modern and within their normal geographic range. The bathymetric range of all species listed except *Donax variabilis* Say encompasses the offshore area under study and extends shoreward to the shallow sublittoral waters close offshore where shells are likely to be transported to the beach by incoming waves. Three species, however, appear in considerably larger numbers in one environment than in another. These are *C. fornicata* (Linné), *Anomia simplex* (Orbigny), and *D. variabilis* Say. This difference could be caused by variations in the number of living animals in the offshore and nearshore zones, thus suggesting that little transport occurs between the offshore area and the beach. In the case of *C. fornicata* and *A. simplex*, however, there are alternate explanations.

35. *Crepidula fornicata* is present in amounts of 10 percent or more in the 2.0- to 10.0-mm fraction offshore and in trace amounts on the beach. However, when the beach was sampled for the second time in September 1982, large whole shells of *C. fornicata* were common in the beach drift although rare in the 2- to 10-mm size fraction. The great majority of shells in the offshore

Table 3

Average Percentage of Mollusk Species in 2.0- to 10.0-mm Size Range

Species	Geographic Range	Bathymetric Range, mm	Percentage at Indicated Location: Gilbert Shoal	Sea-floor	Beach
Pelecypods					
Aequipecten gibbus (Linné)	NC-FL	1.8-9.1	0.2	0.2	
Anadara brasiliana (Lamarck)*	NC-TX	Shallow			
Anadara ovelis Bruquiere*	MA-TX	1.8-30.5			
Anadara transverse (Say)*	MA-TX	Below LW	0.9	1.6	
Anomia simplex Orbigny*	NY-FL	Shore-30	10.7	7.5	2.7
Chione grus (Holmes)	NC-FL	1.8-15.2	0.7	1.0	1.0
Chione intapurpurea (Conrad)	NC-TX	3.7-18.3	0.7	1.7	2.7
Corbula dietziana C. B. Adams	NC-FL	6.1-61.0		0.2	0.3
Crassinela lunulata Conrad	NC-FL	0-550.0			0.3
Crassostrea virginica (Gmelin)*	Canada-TX	Estuarine			
Dinocardium robustum (Lightfoot)*	VA-TX	0.91-30.5			
Divaricella quadrisulcata Orbigny	MA-FL	1.8-61.0		0.1	
Donax variabilis Say*	VA-TX	Beach	Trace	Trace	17.1
Glucameric undata (Linné)*	NC-FL	0.91-24.4	1.2	0.7	
Mercenaria mercenaria (Linné)*	Canada-FL	0.61-12.2			
Noetia ponderosa (Say)*	VA-FL	Shallow			
Tellina alternata Say	NC-TX	1.8-36.6	0.3	0.3	
Trachycardium muricatum (Linné)*	NC-TX	1.8-9.1			
Venericardia tridentata (Say)	NC-FL	1.8-61.0	0.2	0.2	
Gastropods					
Crepidula fornicata (Linné)*	Canada-TX	--	10.6	12.5	Trace

* Occurs also as large shells in beach detritus.

cores were whole or nearly whole juvenile specimens. At this stage, *C. fornicata* has a rather thin fragile shell which, if transported to the beach environment, would likely be fragmented. Small fragments of this species can be identified only where they contain part of the nuclear whorl or portions of the shelf on the underside still joined to the body segment. Consequently, there may be a substantial number of *C. fornicata* fragments in the beach sediments which cannot be identified as such.

36. *Anomia simplex* also has a thin friable shell at all stages of growth and probably breaks into many small fragments soon after introduction into the turbulent waters of the surf zone and lower beach. The pearly translucent luster of the shell aids in identification, but it is likely that the majority of fragments are reduced to very small pieces in a relatively short time.

37. The most significant element of the molluskan fauna is *D. variabilis* which occurs in quantity on the beach but is nearly absent offshore. Only three fragments (out of nearly 3,000) were identified in all of the offshore core samples. On the beach, this species makes up an average of 10 percent or more of all particles larger than 0.850 mm (see tabulation below). Unlike the other species of mollusks in the study area, *D. variabilis* has a very limited bathymetric range confined to a narrow zone of the lower foreshore and shallow sublittoral where they have adapted to the turbulent local conditions. Fragments of the shell of *D. variabilis* can usually be identified even in relatively small and beach worn specimens due to the radial ornamentation consisting of bands of different opacity radiating out from the umbonal region. Milky concentric bands crossing the radial bands on part of the shell, hinge structure, coloration, and marginal dentation are also useful in identifying some fragments.

	Average Percent of *D. variabilis* in Indicated Size Range, mm									
	2.0-10.0		0.850-2.0		0.425-0.850		0.250-0.425		0.125-0.250	
Environment	T*	C*	T	C	T	C	T	C	T	C
High water			10.5	10.8	1.8	2.9	0	0	0	0
Near coastline			11.0	11.3	1.7	2.7	0	0	0	0
Backshore			9.5	10.2	2.4	3.8	0	0	0	0
Backrush	23.0	23.0	9.4	9.4	9.8	1.8	2.6	0	0	0
Uprush			11.8	12.2	1.7	2.5	0.2	0.5	0	0

* T = percent of total particles; C = percent of calcium carbonate particles.

38. Because of its many identifying features and limited bathymetric range, *D. variabilis* is an excellent natural tracer for beach sediments. The fact that only a few fragments of this species were found offshore is a good indication that little material from the beach has been contributed to the offshore area. Because of their limited range, the fragments could not have originated offshore except from relict deposits. Their rarity in offshore cores indicates that such is not the case in the study area.

Barnacle Plates

39. Barnacles are important contributors to the offshore sediment of the study area. On Gilbert Shoals and the surrounding seafloor, an average of approximately 30 percent of the sediment particles over 0.425 mm are barnacle shell fragments (see tabulation below). On the adjacent beaches barnacle fragments average only about 4 percent of the particles over 0.425 mm in diameter.

Size Range mm	Average Percentage of Occurrence On Shoals	Off Shoals	Beach
2.0-10.0	43.6	27.4	1.8
0.850-2.0	61.0	62.0	7.26
0.425-0.850	25.7	34.4	3.16
0.250-0.425	8.5	11.5	0.74
0.125-0.250	0.7	0.6	0.1
Average	27.9	27.2	2.6

40. Nearly all of the barnacle fragments occurring in the study area sediments appeared to be *Balanus amphitrite* Darwin (probably in most cases *Balanus amphitrite niveus*), a prolific and widely distributed species occurring in great numbers where suitable substrate for attachment occurs. Each individual of this species constructs and lives in a conical shell made up of eleven individual plates. These include two end plates, four lateral plates, and two pairs of opercular valves used to open and close the aperture at the summit of the cone. In addition, there is a basal plate attached directly to the substrate. Therefore, when the barnacle dies and its shell is broken, each individual barnacle contributes up to eleven sand-size particles to the local sediment supply. Considering how prolific these animals are in favorable living conditions, it is not surprising that they can contribute sizable quantities of sand-size sediment. Nevertheless, shelf sediment of the southern part of the Florida Atlantic shelf is unusually high in barnacle plates. This is probably due to very favorable living conditions, large areas of outcropping rock which provide suitable substrate, and a low input of terrestrial sediment.

41. Even where broken, worn, or altered by boring organisms, *B. amphitrite* plates are usually identifiable because of their distinctive shape, tubiferous wall structure, and narrow gray or purple stripes on lateral and end plates. Sculpture, shape, and ornamentation of the opercular plates are

also good identifying features even in degraded condition. Thus, it is probable that most barnacle fragments have been identified in the counts of size fractions over 0.425 mm. In small particle sizes few retain identifying features.

42. The difference in content of barnacle plates between offshore cores and the beach samples is striking, particularly in the material larger than 0.425 mm. This strongly suggests that little sediment from Gilbert Shoal and the surrounding seafloor is reaching the beach. Moreover, many if not most of the barnacle plates in beach sediment may be derived from animals living on rock outcrops or other suitable substrate in the shallow sublittoral zone, close to the beach and not far from the shoal area. A more detailed consideration of the barnacle fragments as indicators of sediment movement is given in Part V of this report.

Foraminifera

43. Foraminifera are minute marine organisms that construct a hard shell or "test" to protect their bodies. Most foraminiferal tests are in the sand-size range (i.e., 0.063 to 2.0 mm). Tests of foraminifera occur in almost all marine sediments that have not been subjected to leaching. Often the discarded tests accumulate in great numbers and in places are the dominant constituent of a sediment deposit.

44. Because of their abundance, small size, and large variety of species, foraminifera are widely used in geology to differentiate sedimentary sequences and determine geological age and depositional environments. Since different types of foraminifera are adapted to particular environments, displaced tests can be used as natural tracers. Also, tests that have been washed out of ancient sediment and carried to the coast can serve to indicate the location of the source deposit.

45. Foraminifera are sparse in the study area, especially in the beach deposits where they are destroyed in the turbulent surf and lower beach zones. However, foraminifera are in sufficient number to determine the assemblages and frequency distribution of species. These data are shown in Table 4.

46. The species listed in Table 4 generally have bathymetric ranges that encompass the study area from shore to seaward of the shoals; thus the assemblages are similar in most particulars. However, the shoal assemblage

Table 4

Percentage of Occurrence of Foraminifera in Study Area Sediments

Species	Percentage at Indicated Location		
	Seafloor	Gilbert Shoal	Beach
Ammonia beccarii (Linné)	20.4	17.5	23.1
Asterigerina carinata Orbigny		1.7	0.7
Augulogerina occidentalis (Cushman)	2.8	1.0	2.2
Buccella hannai (Pheger and Parker)	0.3		0.7
Cibicides lobatulus (Walker and Jacob)	1.2	3.4	1.5
Elphidium advenum (Cushman)	3.8	16.1	1.5
Elphidium articulatum (d'Orbigny)	1.7	3.8	1.5
Elphidium excavatum (Terquem)	40.5	13.0	35.1
Elphidium discoidale (d'Orbigny)	3.3	2.1	6.0
Elphidium galvestonense (Kornfeld)			1.5
Elphidium mexicanium Kornfeld	1.8	3.8	9.7
Elphidium poeyanum (d'Orbigny)	0.5	1.0	
Total *Elphidium*	51.6	39.8	56.8
Florilus atlanticus (Cushman)	5.7	8.9	4.5
Hanzawaia concentrica (Cushman)	4.8	6.5	3.7
Eponides repandus (Fichtel and Moll)	0.1		0.7
Quinqueloculina compta Cushman		1.7	0.7
Quinqueloculina jugosa Cushman		1.0	0.7
Quinqueloculina lamarkiana d'Orbigny		1.4	
Quinqueloculina seminula (Linné)		3.1	
Quinqueloculina vulgaris d'Orbigny		1.4	0.7
Quinqueloculina spp.	5.9	6.2	3.8
Total *Quinqueloculina*	5.9	14.8	3.8
Reusella atlantica Cushman	1.3	0.7	
Rosalina advena	0.5		
Rosalina floridana (Cushman)	3.4	2.1	
Rosalina floridensis (Cushman)	0.2	0.7	
Textularia spp.	1.3	2.7	

differs significantly from the beach and surrounding seafloor in the much higher frequency of *Elphidium advenum* (Cushman), in the total percentage of the various species of *Quinqueloculina*, and in the relatively low number of *Elphidium excavatum* (Terquem).

47. It is of interest to note that shoal areas in the Fort Pierce area to the north contain a much higher percentage of *E. advenum* than the surrounding seafloor. Presumably the shoals provide a more favorable environment for the increase of this species. The relative abundance of the species of *Quinqueloculina* is possibly due to favorable environmental factors as well, or possibly to the larger and heavier test of this genus concentrated by

winnowing of smaller genera from the shoal sediments. Winnowing may be the cause of the low frequency of *E. excavatum* as well.

48. The data from Table 4, especially that pertaining to *E. advenum*, suggest that no large-scale transfer of sediment exists from Gilbert Shoal to the shelf floor or to the adjacent shore.

Oolites

49. Oolites are small subspherical calcium carbonate particles formed by precipitation around a nucleus of some organic or inorganic bit of matter. Oolites have been reported from the Atlantic shelf and upper slope of Florida (Terlecky 1967, Pilkey et al. 1969, Macintyre and Milliman 1970, Field and Pilkey 1972) and from beach and nearshore sediments in the Cape Canaveral region (Field and Duane 1972, Field and Pilkey 1972).

50. Oolites occur in the sediments of Gilbert Shoal and the adjacent seafloor and beaches. Most are found in the 0.250- to 0.425-mm size fraction. These do not appear to originate from the rocks which outcrop on the beach and in the nearshore area since no oolites have been seen in examination of these rocks. Oolites do occur in a rock found in core number 6 offshore but these are much smaller than most of those found in the overlying sediment. The most likely source is from outcrops of oolitic sediment and rock near the shelf edge. Cores in the outer shelf, a short distance northward of the study area off Fort Pierce, penetrated exposures of unconsolidated to lithified calcareous rock containing abundant oolites (Meisburger and Duane 1971). This unit seems to be the ultimate source for oolites found in the study area.

51. Because of the relatively sparse number of oolites in most samples, their abundance was determined with respect to the weight rather than the total number of particles in the sample counted. Table 5 shows the average number of oolites occurring in 0.25 g of sediment from Gilbert Shoal, the seafloor, and adjacent beach.

52. If the source of oolites is presumed to be shelf edge exposures of oolitic material, onshore transport is strongly suggested. It is possible that oolites on the beach might have come by littoral drift from updrift beaches. However, the potential updrift sources are situated adjacent to a shelf area and subject to a wave climate similar to that of the study area. Thus, if onshore transport occurred in one area, it would most likely occur in

Table 5

Percentage of Oolites in 0.25 g of Sediment for 0.250- to 0.425-mm Size Fraction

Gilbert Shoal			Seafloor			Beach		
Core No.	Depth	% Oolites	Core No.	Depth	% Oolites	Location, year	Site	% Oolites
3	-1.0 ft	96.0	5	Top	46.2	NC-SC, 81	5, high water	15.6
3	-16.0 ft	20.5	5	-8.0 ft	46.4	NC-SC, 81	5, back-rush	3.8
7	Top	32.8	8	Top	5.0	NC-SC, 81	6, high water	7.4
7	-18.0 ft	69.5	10	Top	20.3	NC-SC, 81	6, back-rush	6.8
11	Top	32.3	10	-3.0 ft	36.0	NC-SC, 81	7, high water	39.8
11	-10.0 ft	34.7	13	Top	14.3	NC-SC, 81	7, back-rush	15.8
12	Top	14.3	13	-8.0 ft	26.5	FL, 82	20, high water	22.0
12	-12.0 ft	45.8	14	Top	21.3	FL, 82	20, back-shore	36.0
15	Top	42.3	16	Top	19.1	FL, 82	20, hole in back-shore	38.8
15	-8.0 ft	12.9	18	Top	46.4	FL, 82	20, back-rush	11.1
17	Top	22.1	21	Top	62.5	FL, 82	20, uprush	9.2
17	-14.0 ft	20.8	22	Top	2.8	FL, 82	21, high water	9.4
20	Top	80.8	23	Top	36.5	FL, 82	21, hole in back-shore	69.7
20	-6.0 ft	25.0		Average	29.5	FL, 82	21, back-rush	8.2
	Average	39.3				FL, 82	21, uprush	10.6
						FL, 82	22, high water	16.0
						FL, 82	22, back-shore	35.7
						FL, 82	22, hole in back-shore	7.7
						FL, 82	22, back-rush	2.1
						FL, 82	22, uprush	4.3
							Average	18.5

the other. In addition, if waves and currents are competent enough to move oolites from the shelf edge to Gilbert Shoal, they could be expected to be capable of moving the oolites in the shallower waters between shoal and beach.

53. In general, the presence of oolites in the study area indicates movement from Gilbert Shoal and the adjacent seafloor to the beach. The extent of this movement cannot be estimated because of the small amount of tracer involved and the great variability in values between samples.

Calcium Carbonate Grain Properties

54. Two properties of the calcium carbonate particles found in the study are roundness and surface texture. These properties have tracer value because of significant differences in these elements between beach and offshore locales. Another but less significant property is grain color. Differences in particle color between beach and offshore sediment exist but are not large.

55. In terms of roundness and surface texture, most calcium carbonate in the study area can be divided into two classes, here designated rounded/smooth and angular/corroded. In general, particles classed as rounded/smooth have fairly rounded grain edges and a smooth to polished surface. Particles classed as angular/corroded generally have angular grain edges and a heavily pitted surface, an aspect often referred to in the literature as "corroded." This latter category (angular/corroded) also includes mollusk shells with little indication of wear on the surface sculpture. Although classification in these categories is relatively subjective and thus liable to operator bias, the consistently large differences in frequency between beach and offshore locales and fairly consistent counts between samples from the same environment indicate that the observed trends are probably real.

56. Table 6 shows the average frequency of rounded/smooth and angular/corroded calcium carbonate particles in beach and offshore locales. Only two size classes, 0.850 to 2.0 mm and 0.425 to 0.850 mm, are covered because of deficiency of grains over 2.0 mm diam in the sparse offshore samples and the poorly defined features of grains smaller than 0.425 mm.

57. The data in Table 6 show a substantial difference in the two grain properties between beach and offshore locales, suggesting little interchange of sediment. However, these differences could be in part due to environmental factors. Smooth grains from the beach, when transported offshore, could

Table 6

Percentage of Grain Properties

Location	Percent Rounded/Smooth 0.850-2.0 mm	Percent Rounded/Smooth 0.425-0.850 mm	Percent Angular/Corroded 0.850-2.0 mm	Percent Angular/Corroded 0.425-0.850 mm
Gilbert Shoal	6.5	25.1	93.5	74.9
Seafloor	7.5	16.4	92.5	83.6
Beach	77.3	56.7	22.7	43.3

acquire a corroded aspect due to the effects of boring organisms present in the offshore area. It is less likely, however, that these grains could have been fractured sufficiently to develop the angularity seen in most offshore particles. In transport of angular/corroded grains onshore, many if not most grains may rapidly acquire a rounded and smooth surface aspect in the high energy surf and beach environment. However, the prominent and deep pitting of offshore particles caused by boring organisms such as the sponge genus *Cliona* is unlikely to be entirely lost by beach wear. For this reason, even though rounded and otherwise smooth, pitted grains on the beach were counted in the angular/corroded fraction.

58. Color is another characteristic of the calcium carbonate grains that exhibits difference between the beach and offshore environments. Table 7 shows the average frequency of three predominant colors in these places. Only two size categories are included because of the difficulty of categorizing color of the particles smaller than 0.425 mm where particles are often multicolored.

59. Table 7 suggests that there is a small but significant decrease of

Table 7

Percentage of Particle Color

Location	Percent White 0.850-0.2 mm	Percent White 0.425-0.850 mm	Percent Gray 0.850-0.2 mm	Percent Gray 0.425-0.850 mm	Percent Brown 0.850-0.2 mm	Percent Brown 0.425-0.850 mm
Gilbert Shoal	79.3	76.9	9.9	13.3	6.7	9.8
Seafloor	86.6	80.1	11.4	12.9	2.0	7.0
Beach	84.8	85.1	3.3	2.4	11.9	12.5

grayish and a concomitant increase in brownish-colored particles in the beach as compared with sediments of the offshore locales. These differences could, however, occur because of the transport of a particle from one environment to another, from the permanently submerged offshore area to the partially subaerial beach.

PART V: QUANTITATIVE CALCULATIONS

60. Natural tracers have proven to be very useful in the study of sedimentary processes and stratigraphy. Although natural tracers may indicate the probable sources of a sediment deposit, they do not generally provide reliable information concerning the quantity of sediment contributed by each source when more than one source is involved. For example, several studies of Atlantic and Gulf coast barriers have concluded that the offlying continental shelf contributes some sediment to the barriers; however, there is little information regarding the amount of sediment involved (see for example Hsu 1960, Giles and Pilkey 1965, and Field and Pilkey 1972).

61. Many, if not most, beaches probably derive sediment from more than one source, i.e., upland and substrate erosion, offshore areas, nearby inlets, and littoral drift. Except for littoral drift, which can be assessed in places with reasonable accuracy, the volumetric contribution of other sources is usually obscure.

62. There was difficulty in assessing sediment volume because most natural tracers used in the past occur in very small quantity, thus the direct contribution of the tracer to sediment volume is usually negligible. An indirect calculation can be made by determining the ratio of the tracer element to all other particles in the source and, assuming concurrent transportation and deposition, calculating the number of particles that would have accompanied the tracer element to the deposit. However, where the tracer element occurs in a very small quantity, such assumptions are weak. This is especially true of heavy minerals, the most commonly employed tracers, due to differences in density and, in some cases, shape from the usual quartz and calcium carbonate that make up the bulk of coastal sediments. These differences often result in selective sorting during transportation with significant alteration of the heavy mineral suite.

63. In this study area, other natural tracers occur in sufficient amounts to allow estimates of the maximum quantity of material being supplied by a source to a deposit. These estimates do not account for all the particles in a deposit, but they do account for substantial amounts. The most important of the nine natural tracer elements used here are barnacle shell fragments and undifferentiated quartz and calcium carbonate particles. The barnacle fragments are most useful in the three large size categories while

quartz and calcium carbonate are most useful in the two smaller size classes where barnacle fragments no longer retain enough recognizable features to be identified. Calcareous rock fragments and the coquina clam *D. variabilis* (Say) are other elements that occur in sufficient quantity to permit estimates of the amount of contribution from a given source.

Calculation of Maximum Contribution

64. A calculation of the probable maximum amount of particles that could have come from a particular source can be made by the following equation:

$$q = \frac{N}{t_s} t_d + t_d \tag{1}$$

where

q = maximum percent of particles derived from the presumed source

N = percent nontracer particles in the source

t_s = percent tracer particles in source

t_d = percent tracer particles in deposit

65. In this calculation the tracer element selected must be more frequent in the source than in the deposit. In calculating the possible reverse contribution, another tracer must be selected. A summary of values for usable tracer elements is in Table 8.

66. As an example of the calculation above, the estimated maximum contribution of 0.850- to 2-mm particles from Gilbert Shoal to the nearby beach will be considered. From Table 8, using barnacles as the tracer, the pertinent values are $N = 34.3$, $t_s = 65.7$, and $t_d = 7.4$. The ratio N/t_s is 0.52 nonbarnacle particles for each barnacle fragment. Assuming that all barnacle fragments on the beach came from Gilbert Shoal, the percentage of nonbarnacle particles that might have accompanied them is $0.52 \times 7.4 = 3.8$.

67. The estimated maximum percentage of particles in this size fraction that could have been transported from Gilbert Shoal is therefore 3.8 (nonbarnacles) + 7.4 (barnacles) = 11.2 percent of total particles. The remaining 88.8 percent of the particles presumably came from elsewhere or were generated by local shell production.

Table 8

Summary of Average Percentage Values for Key Constituents in the Larger Size Fractions

Tracer Elements	Percentage at Indicated Location: Gilbert Shoal	Seafloor	Beach
2.0-10.0 mm Particle Size			
Barnacles	44.6	29.5	4.4
Donax variabilis (Say)	tr*	tr	7.7
Rock fragments	0	0.21	5.9
Calcium carbonate	100	100	100
Quartz	0	0	0
0.850-2 mm Particle Size			
Barnacles	65.7	69.5	7.4
Donax variabilis (Say)	tr	tr	10.4
Rock fragments	0.09	0.75	4.3
Calcium carbonate	100	99.9	96.2
Quartz	0	0.1	3.8
0.425-0.850 mm Particle Size			
Barnacles	27.3	32.4	3.1
Donax variabilis (Say)	tr	tr	1.9
Rock fragments	0.5	0.96	1.8
Calcium carbonate	91.8	95.2	65.0
Quartz	8.2	4.8	35.0

* tr = 0.1 percent.

Transport from Offshore to Beach

68. Calculations of the estimated maximum transport from Gilbert Shoal and the seafloor to the beach can be made using barnacle fragments, calcium carbonate content, and angular/corroded calcium carbonate particles as tracer elements. Barnacle fragments are the most useful tracer of movement from offshore to the beach because there is a large difference in barnacle plate content between the two areas. It is thus possible to account for a larger amount of sediment as either from or not from the offshore locales.

69. The tabulation on the following page contains results of calculations by the procedure discussed above for the three larger size classes using barnacle fragments as tracers. The tabulation covers only three larger size

classes because barnacle fragments usually cannot be identified in smaller particle sizes.

Size Class, mm	Percent From Gilbert Shoal	Percent From Seafloor
2.0-10.0	9.9	14.9
0.850-2	11.2	12.4
0.425-0.850	11.3	9.6

70. In the two smaller size classes, the tracer elements employed for larger particles are too small to be useful. However, there are substantial differences in quartz and calcium carbonate content between the beach and offshore locales, and these elements can be used as tracers. The tabulation below shows the estimated maximum percentage of particles under 0.425 mm that could have been transferred to the beach from offshore. This calculation uses undifferentiated calcium carbonate as a tracer and, for purposes of the calculation, considers that all of the calcium carbonate on the beach came from offshore. It seems likely, however, that some of the calcium carbonate on the beach is derived from local shell production in the shallow sublittoral; consequently, the estimated maximum values are probably high.

Size Class, mm	Percent From Gilbert Shoal	Percent From Seafloor
0.250-0.425	49.8	46.1
0.125-0.250	32.6	51.0

71. Summarizing the foregoing discussion of possible transport of sediment from offshore locales to the beach, data from tracer elements suggest that in all size categories from about half to as much as 80 percent or more of the beach sediment particles are derived from some source other than the offlying Gilbert Shoal and surrounding seafloor.

Beach to Offshore Locales Transport

72. Calculations of the estimated maximum transport from the beach to Gilbert Shoal and the seafloor can be made using rock fragments, *Donax*, and quartz as tracer elements. Since *Donax* and rock fragments are virtually absent in the offshore locales, a different procedure is used to calculate the estimated maximum contribution. This is made by considering the number of particles that could have been transferred from the beach to offshore locales

without including at least one rock fragment or *Donax* in a normal count of 300 particles. For example, Table 8 shows that in the 0.850- to 2.0-mm size fraction, 3.9 percent of the particles are rock fragments. The ratio of rock fragments to other tracer particles on the beach is 100/3.9 = 25.6 other particles to one rock fragment. It seems probable that up to 25.6 percent of 100 particles in the offshore locales could have come from the beach without including at least one rock fragment. Since no rock fragments were encountered in a count of 300, the estimated maximum is taken as one third of this figure or 8.5 percent.

73. The tabulation below shows the estimated maximum beach contribution to offshore locales using rock and *Donax* fragments individually and combined as tracer elements. Data for the 0.425- to 0.850-mm size fraction is of marginal value because most of the rock fragments from the coarser coquina have probably been reduced to single elements in this size class and are no longer recognizable as rock.

	Percentage Transported from Indicated Tracer		
Size Class, mm	Rock Fragments Only	*Donax* Only	Rocks and *Donax* Combined
2.0-10.0	5.6	1.4	1.2
0.850-2	8.5	3.2	2.3
0.425-0.850	18.5	17.7	9.0

74. In the small size classes, quartz is used as the tracer element. The results of calculating the estimated maximum beach contribution to the two offshore locales is shown below. Note that the 0.425- to 0.850-mm class is also included because it provides a more refined estimate than can be obtained using rounded/polished grains as tracers.

Size Class, mm	Percent From Gilbert Shoal	Percent From Seafloor
0.425-0.850	23.5	13.7
0.250-0.425	41.9	32.2
0.125-0.250	38.4	46.1

Discussion

75. All of the tracer particles used in this investigation were found in the three environments studied, i.e., Gilbert Shoal, the seafloor, and the beach. However, *Donax* and rock particles were virtually absent from offshore

locales. With the exception of *Donax*, the animals which contributed organic tracer particles have living ranges that encompass the entire study area, and thus could have been in the environments as a result of indigenous growth rather than transport. Consequently, it cannot be ascertained whether, for example, barnacle plates found on the beach came from the offshore shoal area by transport or had grown in the shallow sublittoral zone just off the beach. In computing maximum contribution, it was necessary to forego this question because there were no species differences or other means to determine if barnacle plates originated offshore or near the beach. Due to large differences between the barnacle content of the beach and offshore area, the resulting maximum value was low enough to provide significant information. In this case, the assumption that all barnacle shell fragments on the beach came from offshore still left the maximum contribution value low enough to indicate that the offshore sediment contribution was of modest proportions.

76. Other potential organic tracer elements occurred in too nearly the same proportions in the various environments to provide any significant information. Even though transport might have been a factor in the distribution, there was no means of making that determination.

77. In the case of inorganic tracer elements such as oolites and heavy minerals, it can be assumed that they have been transported to any environment other than their place of origin. However, in coastal areas these particles often become widely diffused by the many and varied agencies of transport. Thus, in this study, the same heavy mineral assemblage was present in the three environments and only differed in terms of frequency distribution and dominant particle size. Consequently, it is very difficult to correlate heavy minerals between a suspected source and a deposit.

78. The oolites found in the study area are also apparently subject to selective sorting on the beach. In this region and in numerous beach samples extending northward to Cape Canaveral, it has been found that in most places the oolite concentrations in the high water and backshore samples are significantly higher--sometimes by several orders of magnitude--than in foreshore samples.

79. Another factor affecting interpretation of the data presented herein is seasonality. While not repetitive the samples of the shoals were all obtained during one sampling effort. The beach samples were collected twice, in 1981 and 1982, but both during the month of September.

Consequently, indications of a low rate of sediment interchange between the beach and offshore locales could be typical of one season or of calm conditions in general, but may prove accurate during stormy seasons or in the aftermath of a single large storm. However, this does not seem likely because most of the tracer elements, and in particular barnacle shell fragments, would appear to have a beach life of at least 1 year, although precisely measured data on beach wear of carbonate particles is not available.

80. If, as it seems, there is little interchange of material between the beach and offshore locales, it is of interest to know the probable source of sediment found in these areas. The most likely source for Gilbert Shoal is the surrounding seafloor. The constituents of sediments in seafloor and shoal deposits are in general similar and in roughly the same proportions. Some differences in proportion might be due to selective sorting during transport. Another possible source of sediment for Gilbert Shoal is nearby St. Lucie Inlet. Two samples from the inlet channel were obtained and compared with beach, shoal, and seafloor samples. In all respects, the inlet material proved to be closely similar to the beach sediment and dissimilar to offshore material.

81. Much of the sediment on the beach may have come from the updrift coast by littoral transport. Samples of the shore from St. Lucie Inlet to well past Fort Pierce were examined and were found to be closely similar to beach material in the study area. Material is undoubtedly derived from shell production on the lower beach and shallow sublittoral, and may be of considerable importance. In addition, important contributions likely come from the breakdown of Anastasia rocks on the beach and in the nearshore area.

82. The findings of this study are applicable only in the general area of St. Lucie Inlet and may not apply to other areas of the coast where different geological and oceanographical conditions exist. The methods used here, however, can be used in other areas where suitable natural tracers can be found.

PART VI: SUMMARY AND CONCLUSIONS

83. An investigation was made of the possible interchange of sediments between Gilbert Shoal near St. Lucie Inlet, Florida, the seafloor surrounding the shoal, and the adjacent beach. Analysis of sediment samples collected from these features showed that several particle types in the sediment were potentially usable as natural tracers indicating sediment transport. Seven tracer elements were selected for study: carbonate/quartz ratio, nonopaque heavy minerals, rock fragments, mollusk shells, barnacle shell fragments, foraminifera, and calcareous oolites. The roundness, surface texture, and color of nonspecific calcium carbonate particles were also analyzed.

84. Analyses of the tracer elements in sediment from the three subenvironments of the study area suggested that there was probably some interchange of sediment. An estimate of the maximum possible contribution of the beach to Gilbert Shoal and the shoal to the beach using barnacle, shell fragments, rock fragments, the mollusk species *Donax variabilis*, and the calcium carbonate/quartz ratio suggested that relatively small amounts of material were exchanged, particularly in the important size classes over 0.425 mm.

85. In the case of the shoal and surrounding seafloor, a close correspondence is found between the types and amounts of the sediment constituents in both places. It is concluded that in all probability most of the shoal sediment is swept up from the adjacent seafloor. The possibility of shoal contributions from nearby St. Lucie Inlet was investigated by analyzing samples from the inlet channel. These were found to be unlike the shoal material and very similar to the beach material; therefore, the inlet probably furnishes little or no sediment to the shoal.

86. Possible sources of the bulk of the beach sediment are judged to be littoral drift, shell production in adjacent waters, and disintegration of Anastasia Formation rocks in and near the beach.

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APPENDIX A: BASIC DATA

The following series of tables presents basic data for the various core and beach samples used to calculate the average values shown in the text tables. Locations of core and beach samples are shown in Figure 2 in the main text.

Table A1

Percentage of Carbonate and Quartz in Beach Samples

Sample		Particle Size, mm							
		0.850-2.0		0.425-0.850		0.250-0.425		0.125-0.250	
Location and year	Site No.	Carbonate	Quartz	Carbonate	Quartz	Carbonate	Quartz	Carbonate	Quartz
				Backrush					
FL, 82	20	94.1	5.9	76.7	23.3	42.2	57.8	35.9	64.1
FL, 82	21	97.7	2.3	7.52	24.8	42.4	57.6	36.1	63.9
FL, 81	5	94.3	5.7	65.0	35.0	42.3	57.7	42.4	57.6
FL, 82	22	96.6	3.4	71.3	28.7	47.5	52.5	33.6	66.4
FL, 82	6	94.4	5.6	69.1	30.9	37.9	62.1	23.4	76.8
				Uprush					
FL, 82	20	94.7	5.3	74.6	25.4	48.4	51.6	30.4	69.6
FL, 82	21	98.0	2.0	65.9	34.1	34.3	65.7	36.6	63.4
FL, 82	22	96.0	4.0	62.4	37.6	43.5	56.5	30.3	69.7
				High Water Line					
FL, 82	20	96.7	3.3	55.1	44.1	40.9	59.1	32.8	67.2
FL, 82	21	97.4	2.6	68.0	32.0	36.3	63.7	39.2	60.8
FL, 81	5	97.1	2.9	51.3	48.7	29.7	70.3	44.0	56.0
FL, 82	22	94.7	5.3	64.8	35.2	38.4	61.6	35.5	64.5
FL, 81	6	96.7	3.3	56.5	43.5	33.3	66.77	34.2	56.8
				Backshore					
FL, 82	20	96.1	3.9	63.1	36.9	32.1	67.9	28.7	71.3
FL, 82	22	93.9	6.1	58.0	42.0	32.9	67.1	23.7	76.3
				Hole Near Coastline					
FL, 82	20	95.3	4.7	56.0	44.0	35.3	64.7	29.6	70.4
FL, 82	21	97.1	2.9	69.5	30.5	41.5	58.5	30.2	69.8
FL, 82	22	98.4	1.6	66.7	33.3	31.2	68.8	34.7	65.3

Table A2

Percentage of Carbonate and Quartz in Offshore Samples

Core No.	Interval	0.850-2.0 Carbonate	0.850-2.0 Quartz	0.425-0.850 Carbonate	0.425-0.850 Quartz	0.250-0.425 Carbonate	0.250-0.425 Quartz	0.125-0.250 Carbonate	0.125-0.250 Quartz
		Particle Size, mm							
2	Top	100	0	97.3	2.7	74.1	25.9	66.9	33.1
3*	Top	100	0	87.6	12.4	64.3	35.7	79.1	20.9
3*	-16.0 ft	100	0	89.4	10.6	68.3	31.7	67.6	32.4
5	Top	99.7	0.3	91.1	8.9	77.4	22.6	76.0	24.0
6	Top	No particles		97.4	2.6	92.9	7.1	56.6	43.4
7*	Top	100	0	93.1	6.9	62.8	37.2	58.2	41.8
7*	-18.0 ft	100	0	91.4	8.6	75.9	24.1	73.8	26.2
8	Top	100	0	98.8	1.2	84.3	15.7	55.0	45.0
9	Top	100	0	98.4	1.6	90.1	9.9	54.8	45.2
10	Top	100	0	95.8	4.2	79.5	20.5	67.7	32.2
11*	Top	100	0	95.9	4.1	68.2	31.8	90.1	9.9
11*	-10.0 ft	100	0	93.2	6.8	80.5	19.5	89.4	10.6
12*	Top	100	0	97.7	2.3	81.4	18.6	58.5	41.5
12*	-12.0 ft	100	0	90.2	9.8	80.4	19.6	77.0	23.0
13	Top	100	0	97.2	2.8	75.0	25.0	56.8	43.2
14	Top	99.1	0.9	98.1	1.9	78.0	22.0	50.7	49.3
15*	Top	100	0	92.6	7.4	75.1	24.9	66.9	33.1
15*	-8.0 ft	100	0	91.2	8.8	72.5	27.5	66.4	33.6
16	Top	100	0	97.4	2.6	75.7	24.3	68.8	31.2
17*	Top	100	0	97.9	2.1	73.3	26.7	61.2	38.8
17*	-14.0 ft	100	0	90.8	9.2	80.8	19.2	79.0	21.0
18	Top	100	0	92.2	7.8	76.1	23.9	56.0	44.0
20*	Top	100	0	85.0	15.0	71.1	28.9	81.3	18.7
20*	-6.0 ft	100	0	89.2	10.8	74.6	25.4	83.1	16.9
21	Top	99.7	0.3	85.1	14.9	85.7	14.3	52.9	47.1
22	Top	100	0	98.4	1.6	82.7	17.3	65.5	34.5
23	Top	100	0	90.1	9.9	64.0	36.2	72.9	27.1

* Shoal samples.

Table A3

Frequency Percentage of Heavy Minerals in Beach Samples

Sample		Mineral Species							
Location and Year	Site No.	Zircon	Rutile	Garnet	Staurolite	Epidote	Sillimanite	Amphibole	Tourmaline
				Particle Size 0.250-0.425 mm					
High Water Line									
FL-NC, 81	5			7.8	40.7	31.4	1.6	1.6	16.7
FL, 82	20			7.1	34.6	31.7	4.2	0.6	21.5
FL, 82	21		1.5	31.1	51.9	12.1	0.3		2.9
				Particle Size 0.125-0.250 mm					
High Water Line									
FL-NC, 81	5	0.6	2.6	14.7	36.7	26.1	1.5	1.8	16.1
FL-NC, 81	6	0.4	6.7	16.1	24.0	34.8	3.0	3.0	12.0
FL-NC, 81	7	0.9	5.6	8.8	15.5	45.2	5.0	1.8	7.3
FL, 82	21	17.2	26.1	25.8	23.9	5.7			1.3
FL, 82	22	1.2	10.4	16.2	27.2	32.4	2.3	2.9	6.9
Backrush									
FL-NC, 81	5		5.0	10.0	24.6	38.3	2.1	3.8	16.3
FL-NC, 81	6		6.0	9.6	17.7	43.1	3.0	7.2	13.8
FL-NC, 81	7		4.2	11.0	26.3	35.7	4.2	7.1	10.1
FL, 82	21	3.0	11.3	13.2	22.2	32.0	0.3	3.0	6.4

(Continued)

Table A3 (Concluded)

Sample Location and Year	Site No.	Zircon	Rutile	Garnet	Staurolite	Epidote	Sillimanite	Amphibole	Tourmaline
					Mineral Species				
					Particle Size 0.125-0.250 mm				
Uprush									
FL-NC, 81	7		1.3	5.2	18.2	48.9	7.8	1.6	16.6
FL, 82	21		4.9	9.8	38.8	37.1	1.3	1.0	7.2
					Particle Size 0.063-0.125 mm				
High Water Line									
FL-NC, 81	4	5.3	9.9	8.6	16.4	49.3	0.3	6.7	3.6
FL-NC, 81	7	42.1	13.6	3.1	8.8	19.7	5.3	6.6	0.9
FL-NC, 81	21	88.4	4.0	1.0		4.3	0.3	2.0	
Backrush									
FL-NC, 81	6	5.5	9.0	5.5	10.6	42.7	3.5	19.6	3.5
FL-NC, 82	7	7.2	3.3	6.2	8.2	52.9	3.6	13.4	5.2
FL, 82	21	5.0	3.8	2.8	3.8	48.0	4.1	29.8	2.8
Uprush									
FL-NC, 81	7	1.9	4.5	2.9	6.8	56.0	3.2	20.1	4.5

Table A4

Frequency Percentage of Heavy Minerals in Seafloor Samples at Top Interval,

Particle Size 0.063-0.125 mm

	Mineral Species							
Core No.	Zircon	Rutile	Garnet	Staurolite	Epidote	Sillimanite	Amphibole	Tourmaline
5			0.6	0.3	51.7	4.0	42.2	1.2
10		0.3	0.3	3.2	43.8	9.7	41.6	1.0
14			0.3	2.5	52.9	1.9	41.4	1.0
18	0.3		3.8	3.3	57.1	5.3	27.5	2.8
21		0.3	0.8	2.4	48.5	5.6	40.1	2.4
22	0.5		2.6	1.0	54.7	1.6	37.5	2.1
23	1.0	2.0	1.0	3.5	48.3	9.0	29.9	5.5

Table A5

Frequency Percentage of Heavy Minerals in Shoal Samples, Particle Size 0.063-0.125 mm

		Mineral Species							
Core No.	Interval	Zircon	Rutile	Garnet	Staurolite	Epidote	Sillimanite	Amphibole	Tourmaline
3	-1.0 ft	0.9	3.9	20.5	7.0	31.4	2.6	33.6	
3	-16.0 ft	0.3	0.9	0.3	2.4	58.2	2.4	30.2	5.2
7	Top	1.3	0.6		5.2	39.6	0.6	51.3	0.6
11	Top		2.0	0.7	3.3	56.3		31.9	6.0
12	Top		0.3	1.3	1.6	41.2	12.0	37.3	5.5
15	-8.0 ft		1.5	1.0	4.1	48.6	0.3	40.3	4.1
20	-4.0 ft	0.6	2.1	1.2	1.2	45.3	2.8	45.0	1.8

Table A6

Frequency Percentage of Heavy Minerals in Anastasia Rocks

From Beach Drift and Outcrops

Sample		Mineral Species							
Year	Site No.	Zircon	Rutile	Garnet	Staurolite	Epidote	Sillimanite	Amphibole	Tourmaline
				Particle Size 0.250-0.425 mm					
82	20-3			4.1	24.5	33.8	4.1	2.8	30.3
				Particle Size 0.125-0.250 mm					
81	4-1		2.4	11.0	15.0	43.3	1.6	12.6	14.2
81	5-3	19.2	22.9	20.4	14.6	16.1	1.9	2.5	2.5
82	20-1	3.8	8.2	9.4	16.4	46.5	3.1	5.7	6.3
82	20-2	3.0	9.8	15.2	22.0	30.3	2.3	9.1	6.1
82	20-3	0.8	7.6	5.4	22.0	46.9	3.8	4.9	8.4
82	21-1		9.1	9.1	13.2	47.1	2.5	8.3	10.7
82	23-1	1.5	4.5	7.5	13.5	42.9	4.5	8.3	10.5
				Particle Size 0.063-0.125 mm					
81	4-1	5.2	6.6	5.0	9.1	54.8	4.1	9.9	3.3
81	5-2	0.6	1.7	2.2	6.3	62.5	8.0	14.9	3.0
81	5-3	3.5	4.7	2.3	4.7	46.2	13.7	19.8	4.9
82	19-1	1.0	4.5	1.6	1.3	49.7	7.9	29.8	3.7
82	20-1	4.5	5.8	8.4	3.6	45.8	3.9	20.4	6.8
82	20-2	6.2	6.8	4.3	4.9	61.1		13.6	3.1
82	20-3	7.1	11.6	5.4	3.6	37.5	6.3	20.5	8.0
82	21-1	2.4	4.2	2.9	6.6	52.8	5.3	21.7	5.0
82	23-1	3.9	4.2	1.9	7.4	50.6	3.5	23.9	4.5

Table A7

Percentage of Rock Fragments on Beach

Sample Location and Year	Site No.	2.0-10.0 T*	2.0-10.0 C*	0.850-2.0 T	0.850-2.0 C	0.425-0.850 T	0.425-0.850 C	0.250-0.425 T	0.250-0.425 C	0.125-0.250 T	0.125-0.250 C
Backrush											
FL, 82	20	6.8	6.8	5.2	5.6	1.6	2.0	0.9	2.1	0	0
FL-NC, 81	5	2.2	2.2	7.0	7.4	1.1	1.7	0.3	0.6	0	0
FL, 82	21	9.3	9.3	4.9	5.0	3.5	4.7	0.3	0.8	0	0
FL-NC, 81	6	1.9	1.9	6.2	6.5	1.5	2.2	0	0	0	0
FL, 82	22	9.1	9.1	8.9	9.3	5.0	6.9	0.3	0.6	0	0
High Water Line											
FL, 82	20			4.2	4.3	0.3	0.6	0	0	0	0
FL-NC, 81	5			1.9	1.9	1.5	3.0	0.2	0.8	0	0
FL, 82	21			5.1	5.2	0	0	0	0	0	0
FL-NC, 81	6			3.6	3.7	0.9	1.6	0	0	0	0
FL, 82	22			3.1	3.3	3.4	5.2	0	0	0	0
Uprush											
FL, 82	20			4.5	4.7	1.9	2.5	0.3	0.7	0	0
FL, 82	21			5.9	5.6	0.9	1.5	0	0	0	0
FL, 82	22			2.3	3.0	0.9	1.4	0	0	0	0
Backshore											
FL, 82	20			2.4	2.5	1.2	1.9	0	0	0	0
FL, 82	22			2.1	2.3	3.2	5.5	0	0	0	0
Hole at Coastline											
FL, 82	20			3.2	3.3	3.0	5.3	3.1	8.7	0	0
FL, 82	21			2.6	2.6	1.2	1.8	0	0	0	0
FL, 82	22			4.8	4.9	1.7	2.5	0.3	0.9	0	0

Particle Size, mm

* T = percentage of total particles; C = percentage of carbonate particles.

Table A8

Percentage of Rock Fragments in Offshore Cores

Core No.	Inteval	Particle Size, mm: 2.0-10.0 T*	C*	0.850-2.0 T	C	0.425-0.850 T	C	0.250-0.425 T	C	0.125-0.250 T	C
2	Top	0	0	0	0	0.9	0.9	0	0	0	0
3	Top	0	0	0	0	2.3	2.6	0.8	1.3	0	0
3	-16 ft	0	0	0	0			0	0	0	0
4A	Top			5.4	5.5	5.0	5.4	0	0	0	0
5	Top	0	0	0.9	0.9	1.3	1.5	1.3	1.7	0	0
6	Top	0	0			0	0	0	0	0	0
7	Top	0	0	0	0	1.4	1.5	0.2	0.3	0	0
7	-18 ft	0	0	0	0			0	0	0	0
8	Top	0	0	0	0	0.6	0.6	0.4	0.4	0	0
9	Top	0	0	0	0	1.3	1.3	0	0	0	0
10	Top	0	0	0	0	0.2	0.2	0	0	0	0
11	Top	0	0	0	0	1.0	1.1	0.2	0.3	0	0
11	-10 ft	0	0	2.6	2.6	0.3	0.3	0	0	0	0
12	Top	0	0	0	0	0	0	0	0	0	0
12	-14 ft	0	0	0	0			0	0	0	0
13	Top			0	0	0	0	0	0	0	0
14	Top	2.2	2.2	3.6	3.6	1.4	1.4	0	0	0	0
15	Top	0	0	0.6	0.6	0	0	0.4	0.5	0	0
15	-8 ft	0	0	0	0			0	0	0	0
16	Top					0.3	0.3	0.2	0.3	0	0
17	Top	0	0	0	0	0	0	0.7	0.9	0	0
17	-16 ft	0	0	0	0			0	0	0	0
18	Top	0	0	0	0	0.7	0.8	0.2	0.3	0	0
20	Top	0	0	0	0	1.1	1.3	0.3	0.4	0	0
20	-6 ft	0	0	0	0			0	0	0	0
21	Top	0.8	0.8	0.3	0.3	1.3	1.6	0	0	0	0
22	Top			0	0	0	0	0	0	0	0
23	Top	0	0	0.3	0.3	0.4	0.5	0.4	0.7	0	0

* T = percentage of total particles; C = percentage of carbonate particles.

Table A9

Percentage of *Donax variabilis* in Beach Samples

Sample Location and Year	Site No.	Particle Size, mm: 2.0-10.0 T*	C*	0.850-2.0 T	C	0.425-0.850 T	C	0.250-0.425 T	C	0.125-0.250 T	C
Backrush											
FL, 82	20	23.9	23.9	10.1	10.8	1.9	2.5	0	0	0	0
FL-NC, 81	5	32.1	32.1	8.7	9.2	1.9	2.9	0	0	0	0
FL, 82	21	16.9	16.9	6.6	6.7	1.6	2.1	0	0	0	0
FL-NC, 81	6	23.0	23.0	10.0	10.4	1.8	2.6	0	0	0	0
FL 82	22	19.3	19.3	11.5	12.0	2.0	2.8	0	0	0	0
High Water Line											
FL, 82	20			7.4	7.8	0.6	1.1	0	0	0	0
FL-NC, 81	5			11.5	11.8	1.8	3.4	0	0	0	0
FL, 82	21			13.6	13.9	1.7	2.5	0	0	0	0
FL-NC, 82	6			10.4	10.8	1.6	2.7	0	0	0	0
FL, 82	22			9.4	9.9	3.1	4.7	0	0	0	0
Uprush											
FL, 82	20			11.2	12.3	2.4	3.2	0.3	0.7	0	0
FL, 82	21			12.4	12.6	1.9	3.0	0	0	0	0
FL, 82	22			11.3	11.7	0.9	1.4	0.3	0.8	0	0
Backshore											
FL, 82	20			10.4	11.4	2.4	3.8	0	0	0	0
FL, 82	22			8.5	9.0	0	0	0	0	0	0
Hole at Coastline											
FL, 82	20			10.3	10.7	1.8	3.2	0	0	0	0
FL, 82	22			10.6	10.8	1.0	1.5	0	0	0	0
Average		23.0	23.0	10.4	10.4	1.7	2.6	tr	tr	0	0

* T = percentage of total particles; C = percentage of carbonate particles.

Table A10

Percentage of Barnacle Plates in Beach Samples

Sample Location and Year	Site No.	2.0-10.0 T*	2.0-10.0 C*	0.850-2.0 T	0.850-2.0 C	0.425-0.850 T	0.425-0.850 C	0.250-0.425 T	0.250-0.425 C	0.125-0.250 T	0.125-0.250 C
Backrush											
FL, 82	20	3.1	3.1	8.8	9.4	3.8	4.9	1.5	3.5	0.3	0.9
FL-NC, 81	5	6.1	6.1	10.5	11.1	3.8	5.8	1.6	3.7	0	0
FL, 82	21	5.2	5.2	10.2	10.4	3.2	4.3	1.3	3.1	0	0
FL-NC, 81	6	5.7	5.7	7.8	8.3	5.6	8.1	1.0	2.6	0.3	1.3
FL, 82	22	1.8	1.8	8.6	9.9	2.3	3.2	2.3	4.4	0	0
High Water Line											
FL, 82	20			4.5	4.7	1.3	2.3	0	0	0	0
FL-NC, 81	5			6.1	6.3	1.5	3.0	0	0	0	0
FL, 82	21			11.1	11.3	2.7	4.0	0.3	0.8	0	0
FL-NC 81	6			3.9	4.0	2.8	4.9	0	0	0	0
FL, 82	22			4.7	5.0	3.1	4.7	0.3	0.7	0	0
Uprush											
FL, 82	20			4.5	4.7	6.1	8.2	1.9	4.0	0.3	1.1
FL, 82	21			6.8	6.9	3.9	5.9	1.5	4.5	0.3	0.8
FL, 82	22			4.3	4.5	2.7	45.3	1.0	2.3	0.3	1.1
Backshore											
FL, 82	20			6.4	6.6	2.4	3.8	0	0	0	0
FL, 82	22			3.7	3.9	1.9	3.3	0.7	2.0	0	0
Hole at Coastline											
FL, 82	20			5.2	5.3	1.8	3.2	0.5	1.3	0	0
FL, 82	21			13.1	13.5	2.7	3.9	0.6	1.6	0	0
FL, 82	22			13.2	13.4	5.0	7.4	0.3	0.9	0	0
	Average	4.4	4.4	7.4	7.7	3.1	4.7	0.82	1.8	0.08	0.28

Particle Size, mm

* T = percentage of total particles; C = percentage of carbonate particles.

Table A11

Percentage of Barnacle Plates in Offshore Samples

		Particle Size, mm									
Core		2.0-10.0		0.850-2.0		0.425-0.850		0.250-0.425		0.125-0.250	
No.	Interval	T*	C*	T	C	T	C	T	C	T	C
2	Top	33.3	33.3	66.9	66.9	34.3	35.3	11.8	15.9	2.2	3.3
3	Top	52.9	52.9	62.4	62.4	10.0	11.5	4.1	6.4	1.2	1.5
3	Top	45.5	45.5	63.1	63.1	23.1	25.8	7.0	10.3	2.0	2.9
4	Top	no data		31.3	31.8	18.6	20.3	8.2	10.6	2.1	2.7
5	Top	no data		60.9	63.0	31.1	34.2	10.8	14.0	0.6	0.8
5	-8.0 ft	25.3	25.3								
6	Top	20.9	20.9			46.6	47.8	18.0	19.4	2.9	5.1
7	Top	39.3	39.3	70.0	70.0	25.4	27.3	6.0	9.6	0	0
7	-18.0 ft	36.4	36.4	54.2	54.2	30.4	33.2	7.2	9.5	0.3	0.4
8	Top	no data		68.2	68.2	30.6	31.0	17.2	20.4	0	0
9	Top	no data		62.5	62.5	60.5	61.5	18.4	20.4	0	0
10	Top	28.0	28.0	61.4	61.4	27.7	28.9	11.6	14.6	0.3	0.5
11	Top	53.4	53.4	64.8	64.8	21.0	21.9	4.8	7.0	1.0	1.1
11	-10.0 ft	42.3	42.3	60.4	60.4	26.8	28.8	5.7	7.1	2.0	2.2
12	Top	54.0	54.0	73.5	73.5	39.5	40.5	14.4	17.7	0.3	0.5
12	-14.0 ft	45.9	45.9	57.1	57.1	18.0	19.9	9.4	11.7	0.7	1.0
13	Top	no data		72.1	72.1	39.4	40.5	9.5	12.6	0	0
14	Top	30.4	30.4	50.3	50.8	36.0	36.7	12.9	16.5	0.3	0.6
15	Top	31.6	31.6	69.9	69.9	37.9	40.3	7.7	10.2	0.3	0.5
15	-8.0 ft	37.2	37.2	55.2	55.2	21.2	23.3	11.6	16.0	0	0
16	Top	no data		53.0	53.0	22.5	23.1	9.3	12.2	0.7	1.0
17	Top	56.7	56.7	68.1	68.1	32.6	33.2	10.7	14.6	0.6	0.9
17	-16.0 ft	38.0	38.0	49.0	49.0	31.4	34.5	12.0	14.9	0.6	0.8
18	Top	no data		56.7	56.7	29.4	31.9	9.8	12.9	0	0
20	Top	46.4	46.4	52.1	52.31	15.4	18.2	5.8	8.1	0.6	0.8
20	-6.0 ft	no data		69.60	69.60	42.40	43.1	10.3	12.5	0.5	0.8
21	Top	36.8	36.8	53.6	53.8	12.9	15.1	4.6	5.3	0	0.
22	Top	no data		69.6	69.6	42.4	43.1	10.3	12.5	0.5	0.8
23	Top	31.9	31.9	67.1	67.1	22.2	24.7	5.2	8.1	2.0	2.7

* T = percentage of total particles; C = percentage of carbonate particles.

Table A12

Percentage Frequency of Rounded/Polished and Angular/Corroded Grains in Beach Samples from Backrush, 2.0- to 10.0-mm Size Fraction

Sample			
Location and Year	Site No.	Rounded/Polished	Angular/Corroded
FL-NC, 81	6	88.0	12.0
FL, 82	20	84.0	16.0
FL, 82	21	81.4	18.6
FL, 82	22	87.1	12.9

Table A13

Percentage Frequency of Rounded/Polished and Angular/Corroded Grains in Seafloor Samples, 2.0- to 10.0-mm Size Fraction

Core No.	Interval	Rounded-Polished	Angular-Corroded
5	Top	5.7	94.3
10	~1.0 ft	5.4	94.6
16	Top	8.2	91.8
21	Top	4.4	95.6
23	Top	5.1	94.9

Table A14

Percentage Frequency of Rounded/Polished and Angular/Corroded Grains in Beaches, 2.0- to 10.0-mm Size Fraction

Core No.	Interval, ft	Rounded/Polished	Angular/Corroded
3	1.0	8.0	92.0
7	4.0	6.3	93.7
12	1.0	11.6	88.4
15	6.0	5.4	94.6
17	14.0	8.1	91.9

Table A15

Percentage Frequency of Particle Colors in Beach Samples

Sample				
Location and Year	Site No.	Gray	Brown	White
		Particle Size 0.850-2.0 mm		
FL-NC, 82	5	13.9	11.1	75.0
FL-NC, 81	6	16.0	12.6	71.4
FL, 82	20	8.0	19.6	72.4
FL, 82	21	23.4	17.0	59.6
FL, 82	22	11.7	9.1	79.2
		Particle Size 0.425-0.850 mm		
FL-NC, 81	5	11.0	17.8	71.2
FL-NC, 81	6	14.3	12.6	73.1
FL, 82	20	10.1	19.3	70.6
FL, 82	21	10.6	18.7	70.7
FL, 82	22	9.5	13.8	76.7

Table A16

Percentage Frequency of Particle Colors in Seafloor Samples

Core No.	Interval	Gray	Brown	White
		Particle Size 0.850-2.0 mm		
5	Top	7.9		92.1
8	Top	14.3		85.7
13	Top	12.2	6.2	81.6
16	Top	11.3	1.9	86.8
		Particle Size 0.426-0.850 mm		
5	Top	22.8	1.0	76.2
8	Top	9.6	10.6	79.8
13	Top	8.7	5.8	85.5
16	Top	10.5	10.5	79.0

Table A17

Percentage Frequency of Particle Colors in Shoal Samples

Core No.	Interval	Gray	Brown	White
		Particle Size 0.850-2.0 mm		
3	Top	6.5	1.9	91.6
7	Top	8.8	12.4	78.8
12	Top	10.3	5.1	84.6
15	Top	12.0	7.4	80.6
17	Top	13.6	6.8	79.6
		Particle Size 0.426-0.850 mm		
3	Top	15.3	13.3	71.4
7	Top	15.1	11.3	73.6
12	Top	15.5	2.7	81.8
15	Top	9.4	9.4	81.2
17	Top	11.2	12.2	76.6